**Experiment 11: Faraday Cages**

**OVERVIEW**

**In this lab you will:**

1. Learn about Faraday cages, and the reason that they work.
2. Consider how Faraday cages can be used practically to improve neural recording experiments.
3. Observe the steps to building a Faraday cage, and perform a test of this cage in a noisy environment.

**OBJECTIVES**

**Before doing this lab you should:**

* review the parameters of neural recording experiments (i.e. the type of signal recorded, the size of the signal, the way that that signal is amplified, etc.);
* learn about charges and electric fields, and the laws governing their interactions.

**After doing this lab you should be able to:**

* explain why a Faraday cage might be important to get good neural recordings;
* describe how a Faraday cage prevents an electromagnetic signal from crossing its surface;
* design and construct a Faraday cage for your own experimental use.

**MATERIALS**

* Metal Screen Mesh
* Wood Strips (3/16 inch by 1/4 inch basswood work well)
* Alligator Clip Cable
* Staple gun
* Heavy duty scissors (“tin snips”)
* Hobby hack saw
* Ruler
* SpikerBox with Cockroach Leg
* “Noisy” power sources…computers plugged into outlets, fluorescent lights, etc.

**INTRODUCTION**

A **Faraday cage** is a container made of conducting material, such as wire mesh or metal plates, that shields what it encloses from external electric fields. In our experiments, a Faraday cage can be used to prevent external electromagnetic interference (**EMI, or noise)** from interfering with our neural recordings. As you know, the neural signals that we are recording are very small (on the order of micro-volts), and we use our Spikerboxes to amplify these small signals to a large enough amplitude that we can hear and record them. Depending on our environment, though, there can be electromagnetic, radio, microwave, or other types of invisible emissions that can travel through the air and interact with the metal needles and wire that we use as electrodes. The metal then propagates the noise signal like an antenna into our neural recordings, interfering with or even drowning out our recordings so that all we hear, in the worst cases, is a radio station! A Faraday cage then can be used to block many of these noise sources.

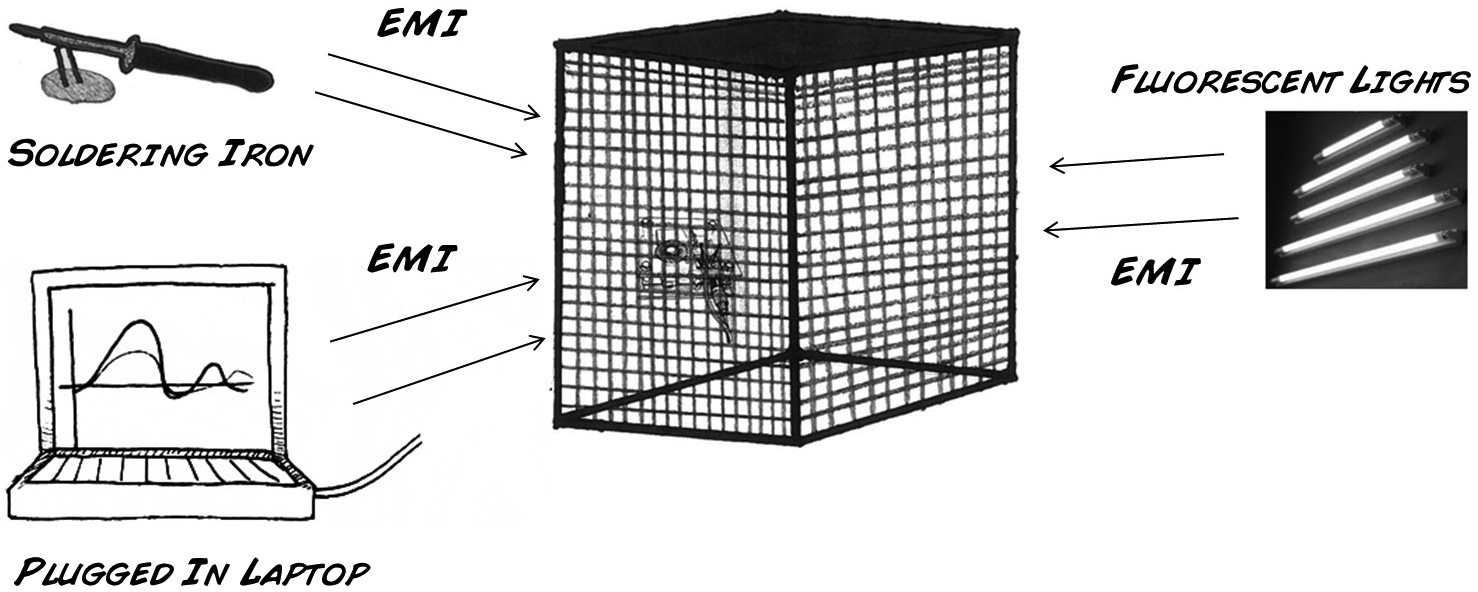
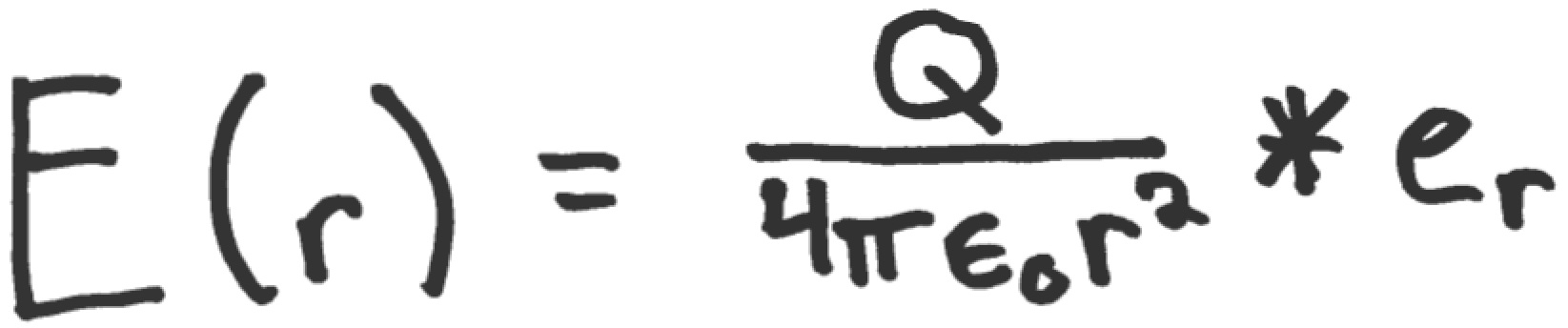


Figure 1: Faraday Cage protecting a Spikebox from several outside electromagnetic interference (EMI) signals.

The Faraday cage is named after 1800s scientist Michael Faraday, but to learn how the cage works we start with another famous scientist, Charles-Augustin de Coulomb. Coulomb did much work on the dynamics of charged particles and the **electric fields** that they generate. Coulomb determined that the electric field, E, at a radius *r* away from a stationary point charge, Q, could be calculated by this equation:

, 

Where is the permittivity of free space and er is the radial unit vector.

If you don’t understand the math (you will one day), it means the electric field strength declines the further away you are from an electric source. If you are driving on a highway and notice a radio station fading, for example, it’s because you are getting further away from the big radio transmitter tower.

The take-home is that this law gives us the foundation for a mathematical relationship that relates charge and electric fields within a fixed volume of space. A Faraday cage encloses such a fixed volume of space, and, if the cage is made of conductive material, the cages’ defining characteristic is that it prevents external charges from inducing electric fields within that volume. Here are two of the main rules that govern this barrier effect:

1. **Coulomb’s Law** demands that the charges in a conductor at equilibrium be as far apart as possible, and thus **the net electric charge of a conductor resides entirely on its surface**.
2. Any net electric field inside the conductor would cause charge to move since it is abundant and mobile, but equilibrium demands that the net force within the conductor is equal to zero. Thus, **the electric field inside of the conductor is zero**.

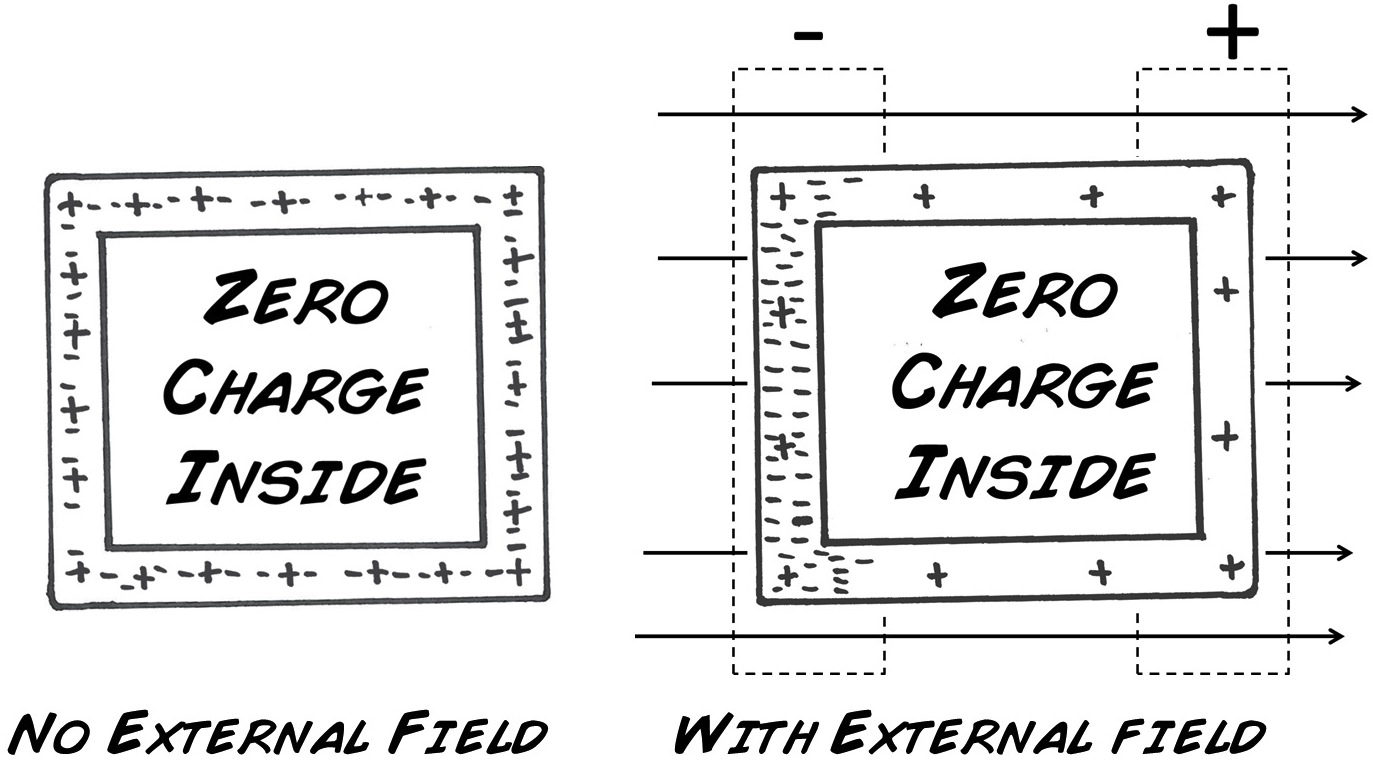
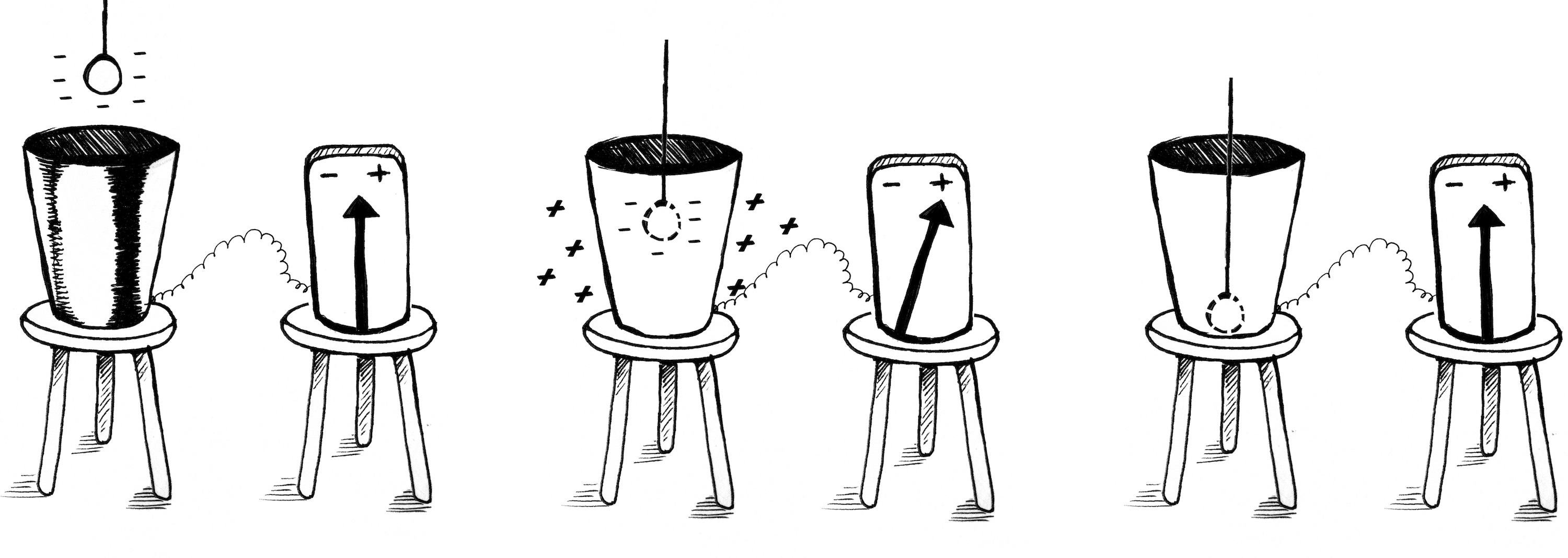
Rule 2 tells us that the electric field inside the conductor at equilibrium is zero, and Rule 1 tells us that the charge of the conductor will be found entirely at the surface (boundary). In other words, the surface of the conducting volume becomes a barrier where charges move to and around the surface to generate fields exactly opposing any charge that seeks to cross the border, thus maintaining an interior free from external electrical interference.

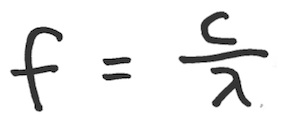
Figure 2: (left) A conducting surface at equilibrium outside of an electric field, with negative and positive charges distributed evenly throughout. (Right) the same surface in an E-field, with negative charges concentrated on left to provide a negative barrier to block the E-field from entering the surface.

Faraday first demonstrated this in a famous ice bucket and metal sphere experiment. Faraday lowered a metal ball charged with static electricity into a metal bucket supported by a wooden chair that insulated the bucket from the ground. When the charged ball was lowered into the bucket without touching the bucket, the charges on the surface of the bucket became redistributed through electrostatic induction. This concept became known as the **Faraday cage principle**.



**Holes in a Faraday cage**

Many Faraday cages, including the one you are building and using, have holes in them for practical purposes (to see inside the cage). Cages made in this way with fencing or mesh material still have conducting surfaces that generate the necessary barriers for electric fields, but there are types of electromagnetic waves such as radio or microwave that could theoretically enter the holes. To prevent this, the cage needs to be built with holes that are sufficiently smaller than the wavelength of these different emissions. Frequency is related to wavelength by the following equation:



Where f = frequency in Hz, c is light velocity, and λ represents wavelength in meters. One rule of thumb often used for Faraday cages to prevent transmission is that the holes need to be no larger than 1/10 of the wavelength of the signal. So for a 3G cell phone that operates at a frequency of 2.1 GHz (2.1 \* 109 Hz), the wavelength = (3 \* 108 m/sec)/ (2.1 \* 109 Hz) = .14 meters. Thus, for a Faraday cage to prevent this noise from entering, the holes in the cage should be smaller than .014 meters (or 1.4 cm).

Using multiple layers of mesh and overlapping them such that the holes on one level are blocked by wire on another level is another effective way to build a barrier for EMI noise.

**Grounding a Faraday cage**

All of the theory listed above tells us that a conducting surface at equilibrium would work to prevent electric fields from entering the enclosed volume, which would thus prevent external fields from inducing currents within the volume that could show up as electrical noise in a recording. However, it should be pointed out that when external signals reach the Faraday cage, there is a transient time period when the surface charges are realigning during which **eddy currents** can form at the surface. Eddy currents are induced in conductors in response to a changing electro-magnetic fields. Eddy currents have inductance, and thus induce electromagnetic fields of their own on either side of the conductive surface. Thus, if the EMI is of high enough frequency and intensity, these eddy currents can produce field changes inside of the cage that show up in our experiments as noise.

One way to improve the EMI barrier capability of the Faraday cage is to connect the Faraday cage to a ground. The mechanisms for how this works aren’t greatly understood, and experimental experience has shown that the best choice for a Faraday ground (e.g. to the wall socket, to the internal ground of the recording device, to the animal itself, etc.) could vary from experiment to experiment. Our best guess is that when the conducting surface of the cage is electrically connected to a ground source, it keeps the entire surface tied to the same potential. Thus, with no means to induce a potential difference at the surface, external EMI is no longer can induce these transient eddy currents.

Here we will examine the effects of the Faraday cage on various conditions when doing neural recordings with the SpikerBox, along with an easy experiment you can do at home.

**PROCEDURE**

**Exercise 1: Building a Faraday cage (video)**

1. Measure out an 8 x 16 inch rectangle of screen metal mesh
2. Cut out the rectangle with heavy duty scissors
3. Measure five 8-inch lengths of wood strips
4. Carefully unroll metal mesh rectangle so that it lays flat
5. Staple wood strips through metal mesh using stapler and light-duty staples
   1. Staple first strip at end of mesh.
   2. Staple second strip 5.5” away from first strip, again length-wise on mesh
   3. Staple third strip 2.5” distant from second strip
   4. Staple fourth strip 5.5” distant from third strip
   5. Staple fifth strip at far end of mesh
6. The wood strips are braces, so after stapling them into place, fold the mesh at each strip to form a rectangular box

**Exercise 2: Testing the ability of the Faraday cage to prevent noise (video)**

1. Set up a standard cockroach leg recording prep as described in Experiment 1
2. Create a noisy environment
   1. Hook up laptop to wall outlet (60-Hz electrical noise)
   2. Turn on soldering iron or other high power appliance.
   3. Turn on fluorescent light
3. Turn on Spikerbox in your noisy environment
   1. Record your observations on noise level vs. neural signal level
4. Clip an alligator clip to the ground on the Spikerbox
5. Place your Spikerbox into your Faraday cage, with cage open
   1. Record your observations on noise level vs. neural signal level
6. Close your Faraday cage but don’t connect the alligator clip to anything
   1. Record your observations on noise level vs. neural signal level
7. Connect your alligator cable to the screen mesh of the cage
   1. Record your observations on noise level vs. neural signal level

**Exercise 3: Testing the ability of the Faraday cage to prevent cell phone activity**

Microwave ovens are examples of Faraday cages, because they are meant to prevent the radiation used to cook the food from escaping into the environment. Aluminum foil is a conductive material, which may also be used to create a Faraday cage.

1. Call your cell phone and make sure that it rings (this is your control).
2. Next, take your cell phone and put it in a (turned off!) microwave.
3. Call the cell phone from another phone. Does it ring?
4. Next, open the microwave door and dial your house phone number on the cell phone. As soon as you hit ‘send’, shut the microwave door quickly. Does your house phone ring?
5. Finally, wrap the cell phone in aluminum foil. Call the cell phone again? Does it ring?

**DISCUSSION QUESTIONS**

1. What are some common “noise” sources that might interfere with a recording experiment? How might those noises enter the recording? How might you keep the noise out? Where would be the perfect place to do a recording?

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1. If a Faraday cage is not connected to an external ground, does it still work? Why does it work even better when it’s grounded? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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1. What do you think a Faraday cage would do to an electromagnetic signal that comes from within the cage? Would someone outside of the Faraday cage be able to receive that signal?

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1. What do you think would happen if you used large hole chicken wire instead of small hole screen metal mesh?

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1. Why do you think cell phone text message noise still interferes with the SpikerBox even though the holes in our Faraday Cage are smaller than the 1.4 cm we calculated?

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